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Electric Seine as a Fish-Sampling Gear in Streams

PETER B. BAYLEY, R. WELDON LARIMORE, AND DAVID C. DOWLING

*Illinois Natural History Survey, 607 East Peabody Drive
Champaign, Illinois 61820, USA*

Abstract.—We describe the basic design, construction, and electric field of a 9.14-m-long, AC electric seine powered by a 1,500-W generator. We determined this seine's efficiency with respect to species number and abundance of various fish taxa in streams of 3–10 m in mean width. The electric seine was fished between block nets and was followed by a rotenone treatment whose efficiency was determined through the recapture of marked fish. We repeated this calibration procedure with a 6.1-m-long, 6.4-mm-mesh minnow seine and a pulsed-DC backpack electrofishing unit at sites with physical conditions similar to those of the electric seine sites. The electric seine method was more efficient for estimating species number and the abundance of common fish taxa. We recommend the electric seine, used in a prescribed manner, for most fish-sampling situations in wadeable streams.

Electrofishing received scant attention for nearly two decades after the pioneer work of Burr (1931), except for some coldwater stream sampling that began in the late 1930s. It was not until Funk (1949) described an electric seine for use in Missouri streams and Larimore et al. (1950) described a boat electrofishing unit that fishing with electricity was employed to any major extent in warmwater systems. Funk's electric seine was immediately adapted for use in Illinois streams and has functioned so well that we assumed many stream biologists were using it. However, correspondence with 18 active North American stream biologists revealed that only 3 used some version of an electric seine. Also, a survey of midwestern North American stream biologists (P. Seelbach, Michigan Department of Natural Resources, personal communication) revealed that the electric seine was only used in 2 of 12 states or provinces. Because of this underuse of an efficient piece of field equipment, we describe the gear as we have developed and used it in streams of Illinois, and we compare its efficiency with those of two commonly used stream gears, a minnow seine and a backpack electrofishing unit.

Design, Operation, and Calibration

Basic design.—An electric seine is an array of electrodes that can be moved up and down a stream for collecting fish. Four basic designs have been developed and used. These designs and their modifications have all used AC electricity and have been employed primarily in streams with warmwater fish communities.

Haskell and Zilliox (1941) used one long screen electrode near the surface and another electrode of bare wire positioned 1.8 m behind the first one and near the bottom in hard-water streams of New York. Funk (1949) used one series of electrodes of metal mesh floating at the surface and a series of bare metal cables of opposite polarity dragging on the bottom. Holton and Sullivan (1954) used two bare parallel wires of opposite polarity stretched across the stream from bank to bank. During the 1950s, Larimore (1961) used a modification of Funk's electric seine: a series of drop electrodes of alternate polarity suspended from a surface power-supply cable.

Each design has operational as well as electrical advantages and disadvantages. For example, the two long parallel electrodes extending across the stream (Holton and Sullivan 1954) create a more uniform electrical field under ideal conditions but are more difficult to move past structures in the stream than a single line of drop electrodes.

Our system is electrically and dimensionally identical to Larimore's (1961) design (Figure 1). The wooden floats used by Funk (1949) to suspend his lead cable were replaced with an air-filled tube that provides continuous flotation to the power-supply line and less resistance to water flow. Instead of one series of electrodes at the surface and one at the bottom, we use alternating drop electrodes suspended from the surface. Other changes have been made for convenience of construction or for operation in the field.

In wadeable streams less than about 12 m wide, we use an electric seine 9.14 m long with 11 drop electrodes 38 cm long and spaced 76 cm apart. The seine has large probe electrodes on each end (Figure 1). It is powered by a portable, 120-V, AC generator with a voltage regulator rated at 1,800 W at 15 A maximum and 1,500 W at 12.5 A continuous output. Each electrode consists of 30.5-

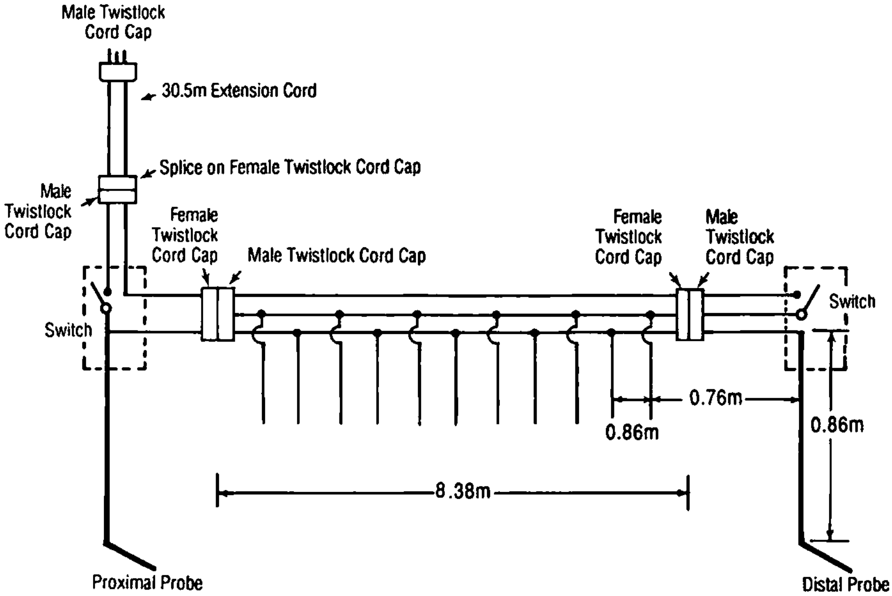

FIGURE 1.—Wiring diagram for a 9.14-m electric seine (not to scale: reduced horizontally).

cm-long, 3.2-mm-diameter brass welding rod suspended from 7.6 cm of flexible stranded-metal cable. The probe electrodes at either end consist of 1.83-m-long, 15.9-mm-diameter copper tubing with the lower 30.5-cm section angled at 130°. A switch box is located midway in the handle. The power supply cable enters the switch box of the proximal probe and is carried across the stream to the series of alternating electrodes and to the distal probe (Figure 1). A three-conductor cable between the probes allows a switch to be installed on the distal probe.

We have described the materials and procedure required for constructing a 9.14-m electric seine in a technical report available from the authors. We use a 15.2-m electric seine in larger streams. This seine is similar in appearance and operation to the 9.14-m seine except that it has eight additional drop electrodes, and an extra person is employed to operate a dip net.

Electrical properties.—We used a simple pair of flat, parallel electrodes, 1 cm square and 1 cm apart, attached rigidly to a wooden meter rule and wired to a Simpson model 470 multimeter, to measure the voltage gradient and current (given the water conductance) at various positions between the seine electrodes. Electrical current through leads was measured by a Mercer model 9701 ammeter. All values are given as root mean squares, which is customary for AC circuits. Under typical field conditions, voltage could be maintained at 115–120 V up to a water conductance of about 1,000 μS/cm. At 1,460 μS/cm, mean voltage dropped only slightly to 113 V (±3 SD) and delivered a maximum generator output that averaged 1,875 W.

We found it difficult to obtain constant in-situ measurements of the voltage gradient close to the drop electrodes without disturbing the electrical field. More reliable results were obtained by interpolation from measurements between the electrodes with a simple exponential function whose parameters were constrained by the total voltage drop measured between electrodes (Figure 2). The maximum voltage gradients were estimated independently as 5.5, 5.1 and 6.9 V/cm at the top, middle, and center positions of the drop electrodes, respectively. These estimates are based on averaged data from two pairs of electrodes and for the habitat conditions shown in Figure 2. The lower gradients of 2.3–3.1 V/cm measured at the end probes were expected because of the probes' larger diameters (Figure 2B). The substrate was soft mud with a conductivity similar to that of the water. Substrates of very low conductivity would change the pattern, particularly if the end probes were held near the bottom.

Mean current flow per electrode for the central nine drop electrodes was 0.42 A (an average of two readings per electrode) under the conditions shown in Figure 2. The end probes each drew 0.48 A, and the drop electrodes adjacent to the end

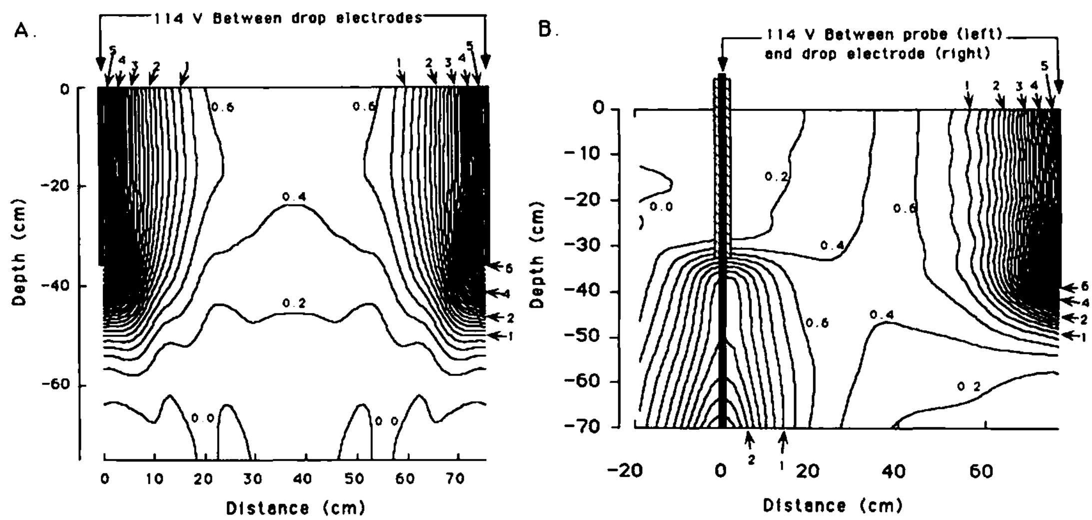

FIGURE 2.—Interpolated mean voltage gradients (V/cm) across the plane of electrodes in water with a conductance of 250 μS/cm over soft mud (A) between two drop electrodes and (B) between an end probe and an adjacent drop electrode. The readings at the curved end of the end probe are projected onto the plane of the handle.

probes drew a mean of 0.55 A. The two end probes together dissipated 16% of the power drawn from the generator in water with a conductance of 250 μS/cm and a depth of 70 cm. The power drawn per end probe was only 8% higher than for each narrow drop electrode. A 950 μS/cm, the total current drawn increased from 5.8 to 17.4 A, and the end probes (combined) still dissipated 16% of the power; however, the voltage gradient at the midpoint between the drop electrodes increased from 0.42 to 0.52 V/cm.

Operation.—The principle of the electric seine is to maintain a curtain of energized water from bank to bank that can be moved up and down the stream and used to block the passage of fish around either end. Each movement of the gear up- or downstream is termed a pass. If block nets are not established to limit the collecting area, we terminate the pass by moving up into a shallow reach that partially, if not entirely, blocks the movements of fish. As we approach the end of a pass without block nets, we may move one end of the electric seine up and across the stream to capture fish swimming ahead. We recommend block nets in streams that lack a riffle–pool sequence to maintain a high and consistent efficiency.

The electric seine is moved at a rate that depends on the water temperature (i.e., more slowly at winter temperatures) and on the substrate. When collecting fish from a gravel or cobble substrate, one must allow time for the fish to drift out from under their hiding places and more time to see and collect fish, particularly small fishes such as darters. One can move faster over smooth substrates but must slow or stop when a school of fish is stunned by the electrical field so that the fish can be collected.

The operators at each end hold the probe in their bank-side hand with the electric seine cable passing in front of them, often against their waders. A dip net is held in the other hand. The probe is carefully worked into the cover of boulders, ledges, roots, and undercut banks. A third person collects fish between the probes and is particularly useful when schools of fish pass through the electric field.

The standard procedure for collecting a sample involves three passes, each covering the entire site. The first pass upstream is followed by a downstream pass back to the starting line and a third pass upstream. The second and third passes commence when the water has cleared. When block nets are used, fish collected from the lower block net after the third pass are included in the sample. This procedure has the advantage of not only picking up fish that may have escaped the electrical field during the first pass but also of retrieving fish that were previously stunned but not collected.

Calibration procedure.—To determine the relationship between catch and the actual fish community or population, a reliable estimate of actual fish abundance must be obtained. Such an estimate is not possible with repeated sampling with the same method because not all fish can be ex-

TABLE 1.—Ranges of physical conditions (means in parentheses) at sites used for calibrations of three fish-sampling gears. Impedance is an estimate (from 0 to 4) of physical resistance to gear operation.

Condition	Electric seine	Backpack electrofisher	Minnow seine
Mean site width (m)	3.4–10.4 (5.9)	4.6–8.3 (6.4)	2.7–8.2 (4.9)
Site length (m)	46–113 (55)	46–91 (69)	39–46 (45)
Maximum site depth (cm)	13–76 (43)	61–76 (69)	30–91 (61)
Turbidity (NTU)[a]	8–50 (22)	1.6–1.9 (1.8)	1.8–62 (22)
Mean current velocity (cm/s)	1.5–15.9 (5.2)	7.6–8.2 (7.9)	0.9–11.9 (7.6)
Temperature (°C)	16–26 (20)	18–22 (20)	15–30 (23)
Conductance (μS/cm)	475–700 (612)	580–680 (630)	520–820 (660)
Impedance	0–3 (0.5)	0–1 (0.5)	0–1 (0.2)

[a] NTU = nephelometric turbidity units.

pected to be vulnerable to capture, and those that are can become less susceptible during repeated exposure to the same fishing operation. We used a calibration method (Bayley 1983; Bayley and Austen 1988) adapted for stream work to determine the efficiency of each primary sampling method (a 9.14-m AC electric seine; a 6.1-m-long, 1.22-m-deep, 6.4-mm-mesh minnow seine; or a pulsed-DC backpack electrofishing unit) with respect to species number, size, and fish taxa. In each calibration, one of the primary sampling methods was used between block nets and followed by the secondary method, a rotenone treatment, for which the efficiency was determined by the recapture of marked fish.

Crews were experienced in the use of all fish-sampling methods. Seventeen sites were selected for calibrations; 10 of these were used for the electric seine, 2 for the backpack unit, and 5 for the minnow seine. The sites sampled by each gear had similar ranges of physical conditions (Table 1). The electric seine operation has been described. The minnow seine was employed in two series of hauls, each of which swept all parts of the site. The first series was made downstream, and the second was upstream. The sites selected had no snags, and hauls were terminated at the block nets to increase fish capture.

The backpack unit (Smith–Root® type VII) was used at 300 V, 60–80 Hz, and a 7–8 ms pulse width. Settings within the frequency and pulse-width ranges were altered to maintain a 1-A output. A second person netted fish. All parts of the blocked area were searched thoroughly during each of three passes. A timer indicated when the current was switched on (23–30 min/calibration). After two passes, the battery was replaced with a fully charged one.

Fish that were captured by the primary sampling methods were marked with caudal fin clips at a 45° angle. Small numbers of additional fish were sometimes obtained for mark and release by sampling similar habitats downstream. Considerable care was taken in handling fish, and only those in good condition were released. A galvanonarcosis trough (Blancheteau et al. 1961) that uses up to 48-V DC was initially used for marking and measuring delicate fish, a category that included all fish less than 10 cm long. Marked fish were kept under observation in aerated, shaded containers for at least 30 min before they were released to their typical habitats within the blocked stretch. Under most conditions, no aftereffect was observed, and recovery to normal buoyancy and swimming ability was fast. Under conditions of high temperature and conductivity, however, some fish did not recover sufficiently for release. With experience, we were able to mark fish in the trough without using electricity and to obtain excellent recovery under all conditions, except for some fish (typically some catostomids and small minnows) that were affected by one of the electrical primary sampling methods.

To further reduce handling of the fish out of water, we measured fish (as total length, in mm) in the galvanonarcosis trough (with or without electricity) against a rule fixed on the bottom. Lengths were converted to the nearest whole cm (rounded down). A mean of 141 fish was marked per calibration, and this quantity covered the species and sizes that dominated each site.

We applied rotenone at the upstream block net with a calibrated backpack sprayer as soon as all marked fish had been released. Before the block nets were set up, river discharge was determined with a Marsh–McBirney® model 2010 flow meter. An estimate of stream discharge was needed to calculate the rate of application and the quantity of a rotenone formulation (Nusyn–Noxfish®, 2.5% rotenone plus 2.5% piperonyl butoxide, a synergist) needed to provide a concentration of 6 mg/L (in terms of the formulation) and to ensure exposure of fish for 10 min. We applied potassium permanganate at 6 mg/L at the downstream block net to match the volume containing rotenone, which had been marked with fluorescein dye to increase visibility. We retrieved fish from all parts of the blocked area and included those swept into the lower block net. All fish were identified and measured. Small fish were preserved and taken to the laboratory to facilitate accurate identification of species and marked individuals.

Data analysis.—The abundance of fish available for capture between the block nets for each primary sampling method (electric seine, backpack unit, or minnow seine) was estimated by correcting the catch of unmarked fish from the secondary sampling method (rotenone) and adding this quantity to the catch of the primary sampling method:

$$\text{abundance} = R_U/(R_M/M) + C;$$

C = number of fish caught by primary method; M = number of marked fish released; R_U = number of unmarked fish caught by secondary method; and R_M = number of marked fish caught by secondary method. The rotenone efficiency, R_M/M, was determined on the basis of the proportion of marked fish that were retrieved (Bayley 1983; Bayley and Austen 1988) and was calculated separately for each calibration. The efficiency of the primary sampling method is the catch of that method, C, divided by the abundance and is expressed as a percentage:

$$\text{efficiency} = 100(C/\text{abundance}).$$

Efficiency was estimated in terms of numbers of species (species richness efficiency = number of species caught by the primary method as a percentage of all species caught by the primary and secondary methods at each site) and the numbers of fish caught within taxa and within length ranges as a percentage of the estimated abundance of each.

Results and Discussion

An analysis of variance of species richness efficiency indicated a highly significant difference among primary sampling methods (F = 7.83, df = 2, 14, P = 0.005; Figure 3A). The species richness efficiency of the electric seine was significantly higher than the other two gears combined (F = 12.73, df = 1, 14, P = 0.003), which were not significantly different from each other (P = 0.7).

The mean efficiency for major species groups (proportion of available fish caught by number) consistently ranked higher for the electric seine than for the other two primary methods (Figure 3B, C). This ranking persisted when species groups were subdivided into length groups of 5 or 10 cm. In sites with physical impediments, the minnow

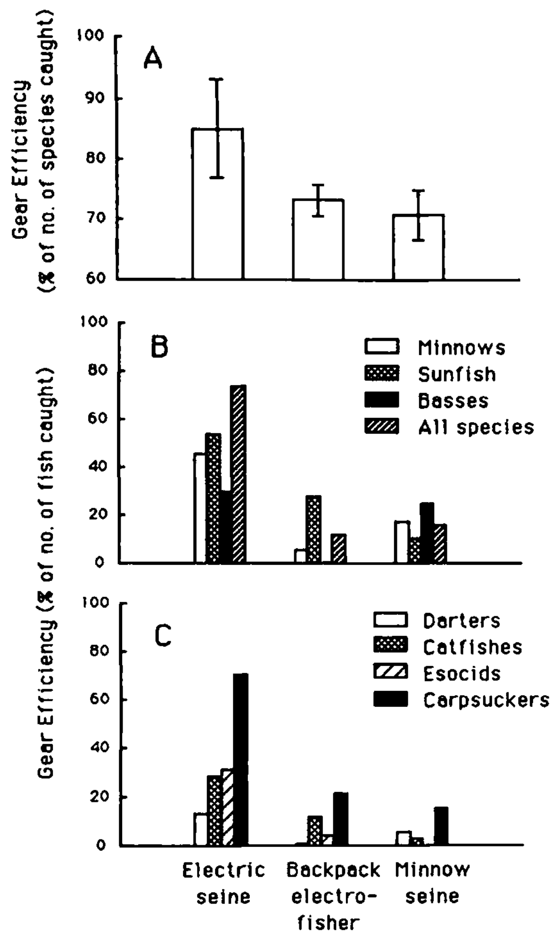

FIGURE 3. Mean gear efficiencies for three primary sampling methods. (A) Species richness efficiency (number of species caught by the primary sampling method as a percentage of all species caught with that primary method and rotenone at each site). Error bars represent ±SD. (B) Efficiency (catch as a percentage of total fish abundance) for minnows (all cyprinids except common carp *Cyprinus carpio*), sunfish (all centrarchids except basses *Micropterus* spp. and crappies *Pomoxis* spp.), basses (black basses *Micropterus* spp. dominated by smallmouth bass *M. dolomieui*), and all fish encountered. (C) Efficiency (as in B) for darters (*Etheostoma* spp. and *Percina* spp.), catfish (mostly bullheads *Ictalurus* spp. and *Noturus* spp.), esocids (mostly grass pickerel *Esox americanus vermiculatus*), and suckers (catostomids, mainly *Carpiodes* spp. and *Moxostoma* spp.). Insufficient data were obtained for basses by the backpack unit and for esocids by the minnow seine; no. = number.

seine would be even less efficient. The backpack unit was relatively poor for catching schooling fish, such as small minnows, in open water.

On the basis of these preliminary calibration results, which agree closely with those of Larimore (1961), we recommend the 9.14-m electric seine for fish sampling in wadeable streams up to 10 m wide, and we recommend longer versions of this gear for sampling wider streams. The electric seine is particularly advantageous when samples are desired that more closely represent the fish community or species diversity (Figure 3A). However, specific factors may increase or decrease the effectiveness or desirability of this method.

The effects of different abiotic conditions and the reactions of different species and sizes of fish to the threat of capture must be confirmed and quantified for the electric seine. Abiotic factors that may affect performance of this gear include stream width, water velocity, bottom materials, water temperature, conductance of the water and bottom, turbidity, depth, and reflected or transmitted light. The last three factors are the most obvious influences on the sighting and gathering of stunned fish. Larimore (1961) found that the efficiency of the electric seine varied also with the size, color, and morphology of the fish. These factors are at least as important as the electric field in determining the effectiveness of an electrofishing method.

Mean efficiency represents only the bias of a sampling gear. The variance of gear efficiency needs to be compared between methods. This variance, which is almost universally ignored is distinct from the usual sampling variance associated with the spatial or temporal distribution of a fish population (Bayley 1985). More calibrations are required to estimate the variance of efficiency so that, in conjunction with the sampling variance, the ability of the electric seine and other methods to predict abundance can be compared.

The design, maintenance, and operation of the gear itself is important. The practical constraints of electrode design produce a variable field of voltage gradients (Figure 2) that, in theory, should not be very effective. However, the electric seine outperforms two other popular methods. Thicker drop electrodes are impractical because they would be too heavy if they weighed enough to maintain a vertical position in the water current. Longer electrodes would increase the depth of the electric curtain, but would require wider spacing to keep adjacent electrodes from touching and draining power through one point. Future calibrations will determine the efficiency as a function of stream depth. Maintenance of the gear is minimal but critical: electrodes need to be cleaned regularly with an abrasive, and generator output to the electrodes needs to be checked.

A major advantage of the electric seine over the minnow seine results from the much smaller effect of physical obstructions. Our preliminary comparisons favored the minnow seine over both electrical gears because physical impedance to its operation (Table 1) was zero or minimal; however, as snags, cobble, or hard cover increase, a larger proportion of the site becomes inaccessible to the minnow seine. Because such obstructions provide habitat to many fish species, minnow seine samples are expected to underestimate species richness and abundances even more than our data indicated (Figure 3). In general, this results in underestimating the value of our better streams in terms of fish abundance and species diversity.

The backpack unit cannot encircle fish and generally traps and stuns fish only associated with cover. Consequently, the electric seine is superior in the capture of schooling cyprinids and catostomids. The end probes of the electric seine effectively stun fish that use cover, such as centrarchids, and our preliminary results indicate that the electric seine is slightly more efficient with this group. A practical advantage of the electric seine is its superior and consistent power source. With the conductances we encountered (Table 1), a second charged battery was required for the backpack unit to complete the sampling procedure.

We experimented with two DC versions of the electric seine (unpublished data) that used a 3.75-kW generator and a Smith–Root® type VI rectifier and different electrode configurations. Lower mortality than with the AC unit was observed, but capture efficiency was much lower because fish were only momentarily affected by the electric current. As soon as the fish were swept past the seine by the water current, they recovered rapidly; this resulted in very inefficient retrieval. Conversely, the AC field stuns fish for a sufficient time for a person to net them in the water or retrieve them from the bottom. We have not exhausted the design possibilities of a DC electric seine, but are discouraged by the practical restriction caused by the heavy and bulky 3.75-kW generator and rectifier that provide the minimum electrical requirements.

Some biologists with whom we have corresponded have perceived problems associated with the electric seine. (1) Two people can operate a minnow seine or a backpack unit, but three people are required to operate the 9.14-m electric seine efficiently. (2) The electric seine with its generator is cumbersome and difficult to carry into remote areas. This problem can be partially overcome by transporting the generator and accessory equipment in a small boat. The boat can be equipped with wheels, so that it serves as a wheelbarrow in shallow areas. (3) Electrofishing damages fish and can cause mortality. Under certain conditions of high water temperature and conductivity, we have observed mortality among catostomids and small cyprinids and to some extent among darters. (4) Operation of the electric seine can be dangerous. Although the voltage gradient approaches 6 V/cm near the drop electrodes (Figure 2), the current is only 0.2–1.3 A, depending on the water conductance. Touching a single electrode is not life-threatening, and the only danger is if someone grabs two electrodes with bare hands. We recommend installing switches at either end of the array, employing an extra person to control the generator and wearing chest waders that do not leak and gloves of high-quality rubber. (5) The electric seine is not available commercially; however, construction is simple, and details can be obtained from the authors.

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